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C. T. MADIGAN'S CONTRIBUTIONS TO GEOLOGY IN SOUTH AND CENTRAL AUSTRALIA

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Summary

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Cecil Madigan (1889–1947) was for many years a Lecturer in Geology in the University of Adelaide. He contributed to our early knowledge of the stratigraphy of Fleurieu Peninsula and of the MacDonnell Ranges, but is best known for his investigations of the Simpson Desert, which he named, and particularly of the age and origin of sand ridges or longitudinal dunes. Many of his conclusions have been modified as a result of later research, but his astute observations and imaginative explanations have earned him an honourable place as one of the very great explorer scientists of this State.

KEY WORDS: Madigan, Simpson Desert, sand ridges, Lake Eyre, Fleurieu Peninsula, MacDonnell Ranges, aerial reconnaissance, evolution of dunes.

Introduction

The year 1989 marked the centenary of the birth of one of the pioneers of Australian geology, C. T. Madigan. Madigan was one of the last of a generation of explorer-scientists who belonged to an heroic age, yet was active recently enough to be survived by many of those who studied under and worked with him. Madigan's contributions to our knowledge of the stratigraphy of the Fleurieu Peninsula and of the MacDonnell Ranges, and of the nature of the sand ridge deserts of central Australia, are reviewed and placed in perspective.

BIOGRAPHICAL SKETCH

Cecil Thomas Madigan (1889–1947) was born at Renmark in the Riverland of South Australia. The son of a struggling irrigation settler associated with the Chaffey brothers, he was one of a family of five (Parkin 1986). The children were still young when their father died on the Kalgoorlie goldfields while attempting to redress the family fortunes. By working as a teacher with the Education Department of South Australia, Madigan's mother contrived not only to rear her family, but also to see them through to a tertiary education. Cecil won a scholarship to the University of Adelaide, taking a Diploma in Mining Engineering, which was later surrendered for a Bachelor of Engineering degree. Madigan was a brilliant student and athlete, and on graduation at the age of twenty-one, in 1910, he was selected as Rhodes Scholar for South Australia. While in England, he was appointed by Douglas Mawson as meteorologist to the Australian Antarctic Expedition and, having arranged deferral of his Oxford studies, he sailed for the Antarctic in the "Aurora" in 1911. In addition to his meteorological duties, Madigan undertook several exploratory sledging journeys from the base camp at Cape Denison, during one of which he carried out a winter reconnaissance of the ice plateau of Adelie Land, experiencing record conditions of cold and wind. In the summer of 1912–13 Madigan led the Eastern sledging party which traversed the sea-ice and coastline of what was later to be named King George V Land, a journey of some eight hundred kilometres which took two months to complete. This undertaking coincided with Mawson's ill-fated Far Eastern sledging journey during which Ninnis and Mertz both perished, Mawson himself struggling back alone to base camp too late to embark on the relief ship. Madigan was chosen as leader of the group of seven who remained behind for a second year pending the return of Mawson, or, failing his return, to mount a search. In recognition of his contributions to the expedition Madigan was awarded the King's Polar Medal in 1914.

This brief period of Antarctic exploration was crucial to Madigan's later scientific life, for he demonstrated both to himself and to the world at large, his capacity for organisation and survival in the most rigorous conditions. The exhilaration of treading where no one else had trod lay latent for several years but it was to emerge and flower once the unknown landscapes of central Australia were within his reach.

On his return from Antarctica, Madigan's Oxford studies were again interrupted, this time by the First World War. He joined the Royal Engineers, (Guards Division) rising to the rank of Captain in 1916, and served in France where he was twice wounded and twice mentioned in despatches.

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Upon demobilization, Madigan completed his studies at Magdalen College, Oxford, graduating B.A. in 1919 with First Class Honours in Natural Science (Geology). In 1920 he was appointed Assistant Geologist in the Sudan Civil Service where he served for two years. Meanwhile Mawson, who in 1905 had been appointed Lecturer in Geology and Mineralogy in the University of Adelaide, was promoted in 1921 to the Chair and almost immediately offered Madigan the post of Lecturer, an appointment which Madigan held from 1922 until his death some twenty-five years later. Madigan had been awarded an Oxford M.A. in 1922, and in 1933 his geological researches, principally in the MacDonnell Ranges of the Northern Territory, were recognized by the conferral of a D.Sc. from the University of Oxford.

As a teacher Madigan was responsible primarily for Second Year students, conducting classes in most aspects of geology as then embraced in the academic curriculum, and, in addition, teaching one-term units in both mining geology and engineering geology.

Initially his research focussed upon the Fleurieu Peninsula, and can be seen as complementing the work of Howchin, Mawson and others, but in the late twenties his physical and intellectual energies were given greater scope by his journeys into central Australia, where folded and faulted terrains, like the MacDonnell and James ranges, excited his attention, and where the sand ridges of the Simpson Desert became an obsession that was to dominate his later years. Madigan himself later named the Simpson Desert after A. A. Simpson, then President of the South Australian Branch of the Royal Geographical Society of Australasia and personal sponsor of the 1939 ground expedition that traversed the dune field.

His University duties were interrupted by World War II when he was appointed Chief Instructor, with the rank of Lieutenant-Colonel, in the School of Military Field Engineering at Liverpool, N.S.W. (Fig. 1). He retired from the Army in 1943, resuming his duties with the University of Adelaide, and, in particular, seeing to press the results of the 1939 investigation of the Simpson Desert.

So much for the record – but what of the man? Madigan was tall, of impressive physique, handsome, and confident in any society. His student blues for rowing and boxing attest his physical stature and interest in fitness; attributes that stood him in good stead in his Antarctic and central Australian expeditions. While serving on the staff of the University of Adelaide, he took a great interest in student affairs, being involved in the Students' Union and in the Graduates' Association, of which he served as Chairman, 1943–4. He was

Fig. 1. Lt Col. Madigan, early nineteen forties (Royal Society of South Australia).

instrumental in founding the Tate Society, an interdisciplinary society for natural science students which organized scientific field camps at various centres of interest in South Australia (Fig. 2).

Madigan was awarded many honours and held numerous professional offices, including Fellow of the Geological Society of London; President of the Royal Society of South Australia 1935, and Verco Medallist 1945; President of the Geographical Section of ANZAAS 1937, and a member of the Council of the Royal Geographical Society of Australasia (S.A. Branch) 1939–1946. His community interests included the Legacy Club, which he served as President, and the Boy Scouts' Association in which he attained the high office of Chief Commissioner for South Australia.

Madigan's many and varied activities made him well-known to the South Australian, and indeed to the Australian, public at large. His scientific reputation however rested on his contributions to the unravelling of the stratigraphy of Fleurieu Peninsula and the MacDonnell and associated ranges in central Australia, on his pioneering efforts in aerial reconnaissance and survey, his observations

Fig. 2. Tate Society expedition to caves near Swan Reach on the River Murray, in 1937: left to right: B. Warhust, P. Nairn, B. Barrien, C. T. Madigan, G. D. Aitchison, R. C. Sprigg, with L. W. Parkin front right (A. F. Pilgrim).

of Lake Eyre, and, most widely and enduringly appreciated, his work on the dunefields of inland Australia, particularly the Simpson Desert (Fig. 3).

FLEURIEU PENINSULA

When Madigan entered the South Australian geological scene, the framework of the State's geology had already been established by such distinguished workers as H. Y. L. Brown, R. Lockhart Jack and Walter Howchin. L. K. Ward was active in his capacity as Director of Mines and Government Geologist. Mawson's interests were concentrated in the basement rocks of the Broken Hill and Olary districts and of the northern Flinders, on the stratigraphy of the Flinders Ranges, and on the ancient glacial sediments exposed in various parts of the State.

Madigan was drawn to Fleurieu Peninsula partly because it had been only cursorily examined by previous workers, but also because, being then served by a railway as far as Willunga, it was relatively accessible at a time when motor cars were comparatively rare; in any case, neither Madigan nor the Geology Department possessed one, nor indeed did Madigan ever own either a car or a driver's licence.

Fig. 3. Map showing places and features mentioned in text.

To place Madigan's Fleurieu Peninsula work in the perspective of the time it is necessary to recall that at this stage Howchin had summarized his own work with the publication of "The Geology of South Australia" (1918). Amongst many other observations, Howchin determined the stratigraphic succession of the Mt Lofty Ranges and concluded that the strata lying unconformably above the highly-metamorphosed inliers exposed in several areas of the Ranges were of Cambrian age, ranging from Lower Cambrian for those units now designated Adelaidean, through to Upper Cambrian for the fossiliferous (Archaeocyathinae) limestones. The 1918 volume includes a cross-section at Sellick Hill, in the north of Fleurieu Peninsula, which provided Madigan with a starting-point for his own investigations. Madigan re-examined this section, describing each unit meticulously, and redrew it using his own revised lithology. He then extended the work along the coast to Cape Jervis and thence to Victor Harbor, running sections wherever rock exposures were adequate and, using the Archaeocyathinae horizon as a marker, traced the succession throughout the area (Madigan 1925).

He compiled a geological map which appeared as a folded coloured plate in this publication. He made the important observation that the greywackes and associated rocks now known as the Kanmantoo Group overlie the Archaeocyathinae Limestone and are therefore Cambrian or younger, whereas Howchin continued to regard them as Precambrian. Madigan obviously had misgivings about the details of his correlations for he soon returned to the area and concentrated particularly upon the scarp of the Willunga Range, establishing the stratigraphical succession from the fossiliferous limestone to the well-identified Sturtian tillite. He constructed a map on a scale of 1 inch to the mile, showing the relationship of the major units. In a paper resulting from this work (Madigan 1927) he drew attention to the anomalous attitude of the sections in which the Proterozoic Adelaide Series overlies the Archaeocyanthinae Limestone, and in a discussion of the problem tentatively canvassed the possibilities of disconformities, overthrusting, or overturned folds to account for the dip reversals.

Although Madigan's 1925 paper is entitled "The Geology of the Fleurieu Peninsula, Part 1. – The Coast from Sellick's Hill to Victor Harbour" (with the English rather than the officially approved American spelling of "Harbour"), the Willunga Scarp paper and a brief note on annelid trails and borings in beds below the Archaeocyanthinae Limestone at Myponga Jetty (Madigan 1926) remain his only further contributions to the area. In a later paper discussing the age of formations on the north coast of Kangaroo Island (Madigan 1928) however, he returned to the structure of Fleurieu Peninsula, referring to his "temerity" in suggesting the possibility of an overturned succession at the Willunga Scarp and, by implication – and incorrectly – reversing the ages of the annelid-bearing beds and coralline limestone he had mapped. Part II of the Fleurieu Peninsula paper seems to have been overtaken by the diversion of Madigan's interest to the Northern Territory, which was in turn stimulated by the aerial reconnaissances he undertook in 1929.

TAKING TO THE AIR

The use of aeroplanes for reconnaissance and photography is as old as the flying machine itself (see e.g. Walker 1951). Aeroplanes were used by both sides during the First World War for general reconnaissance and artillery spotting, as well as for the strafing and bombing of enemy positions. And during the early twenties O.G.S. Crawford and his colleagues in England began to realise the immense possibilities of air photographs for the detection of archaeological sites, for they revealed patterns that are not discernible on the ground. Even before the War, however, in 1909 or thereabouts, Hubert Wilkins (from Mount Bryan, in the Burra district of South Australia) had, rather precariously, taken photographs of parts of southern England perched astride the body of an aeroplane between the cockpit and the propeller, just – but only just – behind the propeller (see Thomas 1962), and in 1913 Sir Henry Welcome, using a box kite as the vehicle for his camera, had obtained air photographs of an archaeological site he was excavating in the Sudan (Crawford 1953).

As previously noted Madigan served on the Western Front during World War I and he must have been aware of the use being made of aircraft for various purposes. He later worked in the Sudan, and may have heard of Welcome's ingenious efforts there. Whatever the background, Madigan pioneered the use of aircraft for scientific reconnaissance and aerial photography in Australia. Using a Westland Wapiti biplane crewed by service personnel, Madigan made nine flights over central Australia in August of 1929. Basically he criss-crossed what he later called the Simpson Desert, and determined that the area contained nothing but desert, and largely dune desert, though he also flew over Lake Eyre and made traverses east and west of Alice Springs in order to view the MacDonnell Ranges (see Madigan 1931). He took overlapping vertical photographs of many parts of the upland, and used the resultant mosaics as base maps on which he later plotted geological information (Madigan 1932a). This is the first recorded

application of aerial photography to geological mapping in Australia.

Flying over the desert Madigan noted the extraordinary regularity and repetition of the sand ridges, likening the view of the dunefields to "a flat pink disc, ribbed from horizon to horizon by the red sandhills . . . " (Madigan 1930, p. 95). From the air Goyders Lagoon was " . . . a maze of watercourses, running in all directions in a black setting of polygonum" (Madigan 1930 p. 93). He noted that the Simpson was much more vegetated than, say, the African deserts (Madigan 1930, p. 96). He was able readily to identify spinifex by its "hollow rings, outward-growing masses from which the centre has decayed and disappeared" (Madigan 1930, p. 95). The aerial view was revealing and Madigan's splendid low oblique photographs grace many of his papers and books.

This series of flights confirmed Madigan in his dedication to the unravelling of the geology of central Australia, for all his later work was devoted to problems noted on these aerial traverses. In particular, his intellectual dedication to deserts in general and the sand ridge deserts in particular dates from this series of aerial traverses undertaken in August 1929.

Fig. 4. Madigan aboard a ship of the desert in central Australia in the nineteen thirties (E. A. Rudd).

THE MACDONNELL RANGES

Madigan's flights from Alice Springs along both the eastern and western MacDonnell Ranges encouraged him to plan field expeditions to the area. He and Mawson (Mawson & Madigan 1930) had carried out some preliminary geological work, using aboriginal names for the various stratigraphic units they recognised and mapped. Thus "Arunta" is the name of a local tribe, and "Larapintine" is derived from Larapinta, the aboriginal name for the Finke in the James Range. Many of these names, suitably redefined in some instances, have been retained and appear on modern geological maps of the region (Wells *et al.* 1970). In 1930 Madigan spent a month in the field, accompanied by a youthful and then recently graduated E. A. Rudd. His experience with camels in the Sudan in the early nineteen twenties suggested to him a means of traversing and mapping the western MacDonnell Ranges toward the Western Australian border, where the outcrops disappear under sand; and the same means of transport was used in the Simpson Desert crossing (Fig. 4).

This was the first systematic geological survey of the MacDonnell Ranges and Madigan carefully measured sections related to a key horizon, the Heavitree Quartzite. The geological map he compiled depicted the structure and stratigraphy of the MacDonnell Ranges (Madigan 1932a, 1932b).

The 1930 expedition extended south of the MacDonnell Ranges to the Waterhouse and James ranges, his cross-sections being the first interpretation of the structure of the now important Amadeus Basin (Madigan 1932). The Horn Expedition (Tate & Wall 1897) had noted the anomalous course of the Finke River as it crossed the fold mountain ranges of central Australia and Madigan (1930, 1931) confirmed this observation. He pronounced the Finke and adjacent rivers as of great antiquity, which is correct, and of antecedent type, which, in the absence of evidence of uplift of the ranges relative to the intervening plains and valleys, is unlikely.

During the 1930 expedition Madigan climbed Mt Sonder and claimed to have been the first European to have done so. It was an interesting facet of the explorer that he insisted on climbing alone although his youthful assistant was anxious to accompany him! His work in the MacDonnell Ranges was a significant contribution to the geology of Australia at a very early stage of the mapping of the continent and a very enterprising project considering the remoteness of the area and the difficulties of travel in those days.

In 1932 Madigan's knowledge of and interest in central Australia led him to being commissioned to assess the prospects at The Granites, where a gold rush had developed. This was during the Depression

and the lure for gold had attracted a large number of people who were ill equipped either mentally or physically to cope with this remote and harsh area. Madigan reported adversely on the gold prospects and a potential human disaster was thus largely averted.

THE SIMPSON DESERT

In addition to introducing Madigan to the folded and faulted uplands of central Australia, the 1929 aerial traverses took him over the most arid areas of the Australian continent, and in particular over extensive fields of longitudinal sand dunes or sand ridges (Fig. 5).

The age and origin of these dune deserts were to become both Madigan's pre-eminent intellectual pursuit and his major claim to enduring and international recognition. Not only were his observations of dunes perceptive but his interpretation of their origin was original and attained considerable notice and acceptance overseas (see e.g. Price 1950). Certain of his observations anticipated some that are now regarded as crucial to the understanding of longitudinal dunes and others broached problems which remain the subject of vigorous debate.

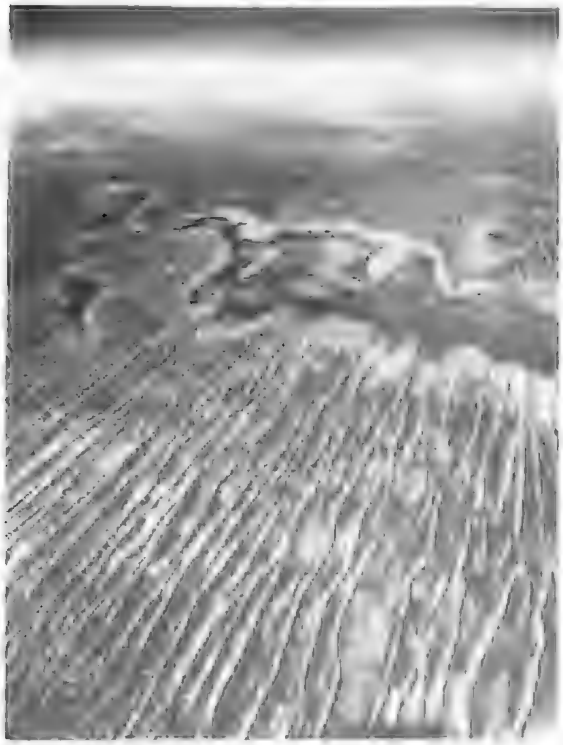

Fig. 5. Oblique air photograph looking north along sand ridges and salinas in the Tirari Desert, just east of Madigan Gulf and south of Cooper Creek. Lake Eyre is in view top left (RAAF).

Madigan (1936, 1937, 1938, 1946) wrote four papers specifically concerned with the sand ridges of central Australia. Though he had flown over the eastern part of the Great Victoria Desert he was mainly concerned with the Simpson Desert, taken here in its broader connotation and embracing the Tirari and the northern part of the Strzelecki deserts as well as the Simpson proper. In addition, many observations are recorded in "Crossing the Dead Heart" (Madigan 1946b).

Of the papers, the first is perhaps the best known probably because it was the first comprehensive scientific account of an Australian dune desert, but also because it appeared in the prestigious *Geographical Review* published in New York by the American Geographical Society. But it is unquestionably the 1946 paper, published, like all the scientific papers generated by the 1939 expedition, in the *Transactions of the Royal Society of South Australia* which stands as Madigan's sandridge testament. It contains a distillation of the observations, experience and consideration of all of Madigan's desert work. Its publication was delayed six years after the expedition by the intervention of the Second World War; and though there is much to be said for rapid publication, the enforced delay allowed time for reflection, and, more importantly, for the reading and digestion of Bagnold's epochal and still unrivalled "The Physics of Blown Sand" (Bagnold 1941).

Madigan was a brilliant observer both in the air and on the ground. His flights over the deserts convinced him of the essential parallelism and continuity of the sandridges (e.g. Madigan 1937) and he confirmed these findings on the ground. He took bearings on the sandridges in various parts of the desert and found that their trend nowhere varied more than 2° from 332° true (Madigan

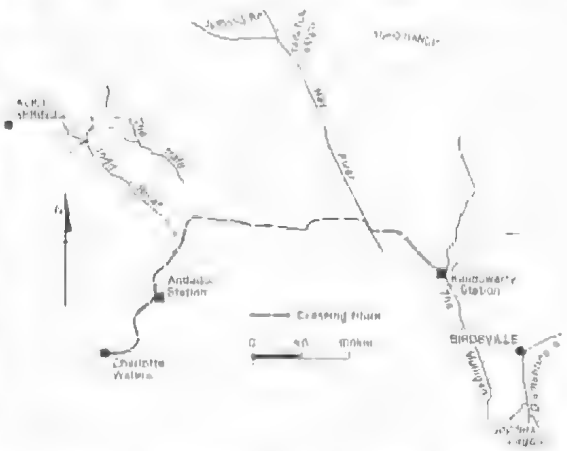

Fig. 6. Route followed by Madigan's party during the crossing of the Simpson Desert, 1939.

1946a, Madigan 1946b). In the course of the 1939 expedition (Fig. 6) he and his party crossed 626 dunes between the Hale and the Mulligan rivers but they saw only one termination of a ridge. Most of the Y- or tuning fork junctions that are typical of the sand ridge desert are open to the south. He noted, as had Gautier (1923, 1935) before him, that the dunefields occupy topographic depressions or "depocentres" (see e.g. Wopfner & Twidale 1967, 1988) and surmised that "The desert is . . . a great alluvial basin, which is still receiving sediment, coarser round the margins, finer toward the lake (Eyre) due to lessening grade. This is surely the origin of the aeolian deposits" (Madigan 1946a, p. 56).

The essential fluvial provenance of the dune sand was confirmed by Carroll's (1944) mineralogical studies; though later work has shown that many of the sand grains have complex histories, having been derived for instance from Permian glacial deposits and Cretaceous marine beds as well as silcrete. But most reach the Lake Eyre Basin and are made available to wind action by way of the many rivers that focus on Lake Eyre (see e.g. Wopfner & Twidale 1967). The red colour of the dunes is due to a ferruginous patina formed on the sand grains. Madigan realised this and pointed out that it forms only in arid conditions, and not, for instance, on beach sands. He remarked (Madigan 1946b, p. 93) that the red patina "takes time to form, so that young dunes are usually white or yellow". Near the Diamantina River he noted that sandy ridges which are built up by sand from the channel are white, but that they gradually become redder toward the interior (i.e. to the north). His practical bent also came to the fore, and enabled him to note that the red veneer was removed when sand grains were boiled in acid! (Madigan 1946b).

Despite the remarkable consistency and repetition of basic dune form, Madigan did not overlook the complexity of the desert, for besides sandridges he encountered salinas and claypans, alluvial flats and gibber plains. He noted the various forms of dune crests and he and his party were forcefully reminded that no desert is rainless when, not for the first time during the 1939 crossing, they experienced rain, and completed the trek into Birdsville along interdune corridors and floodplains heavy with mud.

Madigan observed that the sandridges vary in height between about nine and 30 m above the adjacent interdune corridors. (It is now known that some of the Simpson Desert dunes are 50 m high, but the 1939 expedition did not encounter these higher features). He astutely noticed that there is a relationship between dune height and spacing normal to dune trend (see also Twidale 1981). Thus, he recorded that near Andado, on the western side of the desert, there are five small ridges which stand on average 123 m apart, in contrast with some large ridges near the eastern margin separated by corridors averaging about 910 m width (Madigan 1946a). The lower slopes or plinths of the dunes are quite well vegetated (mainly spinifex and canegrass), though dunes more than about 15 m high have crests essentially devoid of any plant cover. The ridges are asymmetrical in cross section, with the western slope more gentle than the eastern. And this is generally correct, although later more frequent observations and repeat photography of the same sites have demonstrated that following strong southwesterly blows the asymmetry may be reduced or reversed (see e.g. Wopfner & Twidale 1967, at Pl. XVI).

On the formation of the sandridges, Madigan (1930, 1936, 1946a, 1946b) followed Aufrère (1928) in relating dune trend to dominant wind and, as in the Simpson "the great majority of sand-moving winds are southerly" (Madigan 1946a, p. 59), the NNW trend of the dunes is due to transport and deposition under the influence of these prevalent strong winds. Madigan vehemently reasserted his earlier-stated views that the longitudinal ridges originated as small wavy ridges or strips of sand which coalesced downwind into fewer, larger straight ridges (Madigan 1936, 1946a). After reading and reflecting on Bagnold's observations and experiments, Madigan (1946a) concluded that the initial sand strips had evolved as a result of transverse instability in the airflow. He denied that longitudinal dunes evolve under the influence of cross winds from barchans, as had been suggested by Bagnold, pointing out that there are no barchans in the Simpson, or indeed in any of the Australian dunefields (e.g. Madigan 1937).

In fact, ephemeral barchanoid forms are occasionally developed in the Simpson Desert (e.g. Wopfner & Twidale 1988) and Lancaster (1980) has described from Namibia evidence strongly supportive of Bagnold's mechanism; but, by and large, Madigan was right in respect of the Simpson Desert sandridges and, indeed, of most fields of longitudinal dunes.

Madigan considered that the dunes have extended not only downwind, but also upwind as sand was plastered against the upwind tails of dunes; the former would be widely accepted as demonstrated by repeat observations (see e.g. Wopfner & Twidale 1988), but the latter is dubious. He suggested that lateral winds built up the ridges, which, when they reach a critical height act as obstacles which prevent further sand transport, so that the interdune corridors tend to be swept clean of sand; "All sand becomes trapped on the ridge and travels along it" (Madigan 1946, p. 59).

Most of Madigan's basic observations stand, but, just as the 1939 expedition compelled him to abandon some of his earlier conclusions, so some of his speculations have perforce had to be modified in light of later knowledge. For example, the available data suggest that the wind regime in the Simpson is bidirectional or bimodal, the strong, sand-moving winds blowing from southeast and southwest (Brookfield 1970). This is consistent with the internal structure of the sandridges which was well exposed by seismic tracks cut latitudinally across the Desert during the early nineteen sixties: cross-bedding clearly indicates winds from both southeast and southwest, and this in turn finds support in the temporally varied asymmetry of the ridges (Wopfner & Twidale 1967; see also McKee & Tibbitts 1964).

Again, Madigan asserted that the desert was "in equilibrium" and not extending downwind into the Toko-Tarlton-Jervis region. He overlooked the partial "circulation" of sand that returns the wind-blown material to the desert and to the Lake Eyre region by way of such rivers as the Hale, Hay, Todd, Georgina and Diamantina. Also, he was unaware of the importance of source bordering dunes (mounds, lunettes) and other obstacles in the initiation of sand ridges (see e.g. Twidale, 1972, 1981; Dulhunty 1983a).

On the other hand some of Madigan's observations have been overlooked and underrated. For example, that longitudinal dunes develop under the influence of bimodal winds has been suggested by various workers (e.g. Wopfner & Twidale 1967; Twidale 1972, 1981) based on analysis of internal structure and on direct observations of changing asymmetry and sand movement, but it is Tsoar (1978, 1982, 1983) who has, by field experiments, demonstrated that the mechanism involves the "crestal deflection of wind from each of the seasonal modal directions, to flow parallel to the crest line on the lee side of the dune" (Tsoar 1988, p. 597). Although Tsoar's work is properly referred to and praised in Thomas' recent review concerned with linear dune development (Thomas 1988), neither author mentions Madigan's 1939 observation that:

> "At Andado, when the wind was about 30 m.p.h. from the southwest and the crests were 'smoking', it was noted that on the side of the crest, the wind at the surface was blowing along the ridge and even upward toward the summit and carrying sand northwards and upwards along the steep slip-slope". (Madigan 1946a, p. 61)

Nevertheless Madigan's work on sandridge development was well received by the international scientific community.

Madigan's views on the age of the dunefields stand in marked contrast with his emphatic certainty regarding the evolution of dunes. His statements on the subject are equivocal and in places contradictory, though on balance, and taking his indirect as well as his explicit statements into account, he seems to have favoured a recent and continuing age for the forms. On the other hand such ambivalence is probably justified, for, as will be recounted, the evidence concerning the age of the dunes is seemingly contradictory and the question is still being argued.

Madigan considered the silcrete which still occupies large areas of central Australia to have been of late Cainozoic age, having been formed as the B-horizon of a soil during what he called "genial" periods of the Pleistocene (Madigan 1938, p. 27, p. 56). He then suggested that the dunes are relic, stating that they formed during a changeover from pluvial Pleistocene vegetation to the present desertic cover of spinifex and canegrass (Madigan 1946a). He attributed the "live" sand of the Cooper and Diamantina to the depredation of the rabbit, and to (over) stocking (Madigan 1938, p. 27). Yet he stated (Madigan 1946a) that the smaller dunes and the flanks of the larger ones are fixed but that the crests of the latter are active, and that sandridge building has been greatly slowed down though it is still not quite dead. He speculated (Madigan 1938) that the desert must surely have been more arid when the sandridges formed. Yet "No valid reason presents itself to justify the widely held view that aridity was greater in the past when the sandridges had their birth", pointing to the lack of evidence for water table lowering or retreat of vegetation (e.g. Madigan 1938, p. 26). Some of these and other statements can be, and have been, taken to suggest that Madigan considered the dunefield to be stable and a relic of the recent past (e.g. Sprigg 1979, 1980). Some, however, can be construed as indicating a belief in the essentially modern age and activity of the dunes.

If aridity is taken to favour dune activity, then, according to Madigan (1946a, p. 62) "aridity may have reached its maximum", and elsewhere he dismissed the possibility of pluvial/arid alternations during the Pleistocene, and considered that there had been a swing to aridity beginning at the close of the Pleistocene glaciation (Madigan, 1946a). Again: "The origin and history of the Simpson Desert sandridge . . . originating when aridity set in during the late Pleistocene by wind action on the alluvial deposits, mainly unconsolidated, on the great plains of the Lake Eyre Basin" (Madigan 1946a, p. 59).

Madigan was evidently unaware of Ratcliffe's (1936, 1937) studies of the southern and eastern parts of the desert which clearly demonstrate the contemporary movement of dunes. Modern, though probably spasmodic, movement of dune ridges has

been measured (Wopfner & Twidale, 1988) and is supported by many types of indirect evidence. Over wide areas the sandridges overlie fossiliferous alluvial or lacustrine sediments of late Pleistocene or even early Holocene age (Wopfner & Twidale 1967, 1988; Mabbutt & Sullivan 1968; Twidale 1972, 1981). Elements of an older dunefield have been noted (Wopfner & Twidale 1967, 1988), and the possibility of pluvial and arid alternations during the Pleistocene cannot readily be ruled out. For instance, the ancestor of Lake Eyre, Lake Dieri, was an immense body of water during the late Pleistocene (e.g. King 1956; Loffler & Sullivan, 1976; Dulhunty 1983b), so, if the climate has changed during the Holocene or Late Holocene it is surely strange that dune trend is not in process of adjustment?

It is clear from Madigan's comments and conclusions that he did – at times perhaps? – believe that the dunes are still active. Implicit in his observation that the dunes bordering the Diamantina near Birdsville are white and therefore young is the conclusion that they are intrinsically contemporary. Similarly the deflection of sand over the smoking dunes at Andado, and the occurrence of small wavy strips or ridges, surely also imply essential contemporaneity?

The reason for Madigan's confused and confusing statements about the age of the dunes is that the problem is itself confused and confusing. By and large, however, he added immensely to our knowledge of sand ridges both in the Simpson and in other parts of the world. In 1950 the late Armstrong Price published a lengthy review of then recent work on dunes in the Sahara and in central Australia. He concluded that "The chief contribution of Madigan's study of sand dunes is its seemingly satisfactory explanation of the origin and development of longitudinal dunes, based on Bagnold's wind-tunnel experiments and on his own field work and study of the literature" (Price 1950, p. 465).

LAKE EYRE

Madigan's interest in and exploration of Lake Eyre began with his flight across the salina in 1929 as part of his aerial reconnaissance of central Australia. The plane flew low over the salt crust, touching down to leave wheel tracks, though not landing on the soft surface. Mound springs were noted and photographed on the western side of the lake but no other water was sighted (Madigan 1930). After the 1939 crossing of the sand ridge desert, Madigan and his party returned to Marree from Birdsville along the eastern shore of Lake Eyre.

During these land traverses Madigan was his usual busy self. Little escaped his notice. The thickness of the salt crust and the slight but definite slope of the lake bed (see e.g. Dulhunty 1987) were determined at several places. It was observed that where the shore trended latitudinally the sand ridges approaching from the south terminated "abruptly and steeply" on the shore, whereas those to the north of the lake bed rose gently over gypseous slopes to merge with the dunes beyond (Madigan 1946a, p. 139).

Shallow, but quite extensive, bodies of water were seen on the lake bed in 1939, but Madigan formed the opinion that the "lake is never covered all over with water at any time" (Madigan 1946a, p. 134). This conclusion has been shown to be incorrect several times over the past 40 years (see e.g. Bonython & Mason 1953; Kotwicki 1986) and is likely to be repudiated again this year (1990). Nevertheless Madigan contributed to the ongoing investigation of Lake Eyre, and Madigan Gulf, a major embayment forming the southeastern part of Lake Eyre North, is named after him.

Conclusion

In physique, character and personality, C. T. Madigan was a man of great stature. His was a questing mind, wide-ranging yet tenacious, imaginative yet rigorous.

His winter sledge journey on the ice plateau of Adelie Land was an extraordinary test of strength, stamina and character, and his travels in central Australia, whether by air or on the ground, and undertaken under conditions that would today be considered arduous, still stand as truly remarkable feats.

Even in Australia, Madigan's field work was constrained both by the absence of base maps other than pastoral maps, by the absence of good roads and by the travel limitations of horse, camel or foot. Eventually he pioneered aerial reconnaissance and aerial photography, and he lived to see the almost universal availability of four-wheel-drive vehicles for outback work, but most of his field work was of the heroic type, and he became a considerable bushman, utterly at ease in the field situation (Fig. 7).

Madigan's values and standards were those of a bygone age but are none the worse for that. He was strongly and actively patriotic. He believed in physical fitness. He lived by the ideal of service. He possessed a great sense of humour. As a teacher he was stimulating, as well as innovative, and always considerate of his students. He was of a practical bent, and he made sure that his students became aware of the mining, engineering and economic aspects of their discipline. Madigan was a natural leader, and as the years passed he found irksome his position as second in command to Mawson,

Fig. 7. Madigan in camp, MacDonnell Ranges, 1930 (E. A. Rudd).

himself also a striking personality. Perhaps inevitably, an element of tension developed between them. As a departmental staff of only two for much of their joint careers, their respective roles were in some measure resolved, particularly in respect of their research areas, when Madigan elected to concentrate his energies on central Australia and on the problems posed by sand ridges.

It has been said that the geomorphological study of deserts has been bedevilled by the enthusiastic amateur responsible for an "unpalatable farrago of descriptive data" derived from rapid reconnaissance surveys (Cooke & Warren 1973, p. 5). Desert landforms and particularly mobile sand dunes are attractive, even spectacular, features. Their nature and origin inevitably raise questions in the questing mind and it is not surprising therefore that "enthusiastic amateurs" or laymen have been drawn into over-imaginative and even imprudent speculations. Charles Sturt, for instance, was puzzled by both the stony desert and the sand dunes he encountered during his journeys in the interior of Australia in 1845. He suggested that the dunes were gigantic ripples formed on an ancient sea floor and later exposed (Sturt 1849); an interpretation that is untenable but at least based in natural processes rather than divine intervention. But scientists like Madigan, though not trained geomorphologists were nevertheless well equipped to make perceptive observations and draw astute inferences from them.

In this regard it is interesting to note that Madigan, like Bagnold, was trained in engineering, a discipline not inimical to close observation and the linking of natural processes and their results. Furthermore it can be argued that lacking the prejudices and constraints that inevitably result from any formal training in a discipline, such "outsiders" have some advantages in that they are more likely to develop unorthodox explanations (see e.g. Carey 1976).

Madigan was a man of eclectic interests. Possessed of a keen eye and abiding curiosity, he had the ability to get to and work in uncomfortable places. He was one of the last of the great scientific travellers. He notably advanced our knowledge of central Australia, so much so that his name will be forever linked with the sand ridges of the Simpson Desert to which he directed so much time and energy and to the nature of which he brought illumination and understanding.

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